The Valuation of Equity Futures on the Tokyo Stock Exchange, 1920-23

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- Commodity futures: hard to tell, since data on storage costs and convenience yield are needed (e.g. Wakita (2001) and Bell, Brooks and Dryburgh (2007)).
- Equity futures: not yet been studied in a historical setting, theoretically much easier to price since no storage or convenience.

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- Debate settled by 1940s.
- Black (1976) showed how to calculate futures options in a constant interest rate situation, and Hilliard and Reis (1998) demonstrate how to price futures under stochastic interest rates.

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- Tokyo Stock Exchange (TSE) founded in 1878 and futures were present from the start, presumably due to familiarity with the concept from rice trading.
- By the early 20th century the TSE was the largest market in Japan (Osaka was the only serious rival) and futures trading was far more important than the small spot market. The futures market may have helped facilitate liquid trading of securities.

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- No marking to market. Makes valuation easier, since these are effectively forward contracts.
- There were three contracts in existence for each stock: delivery at end of current month, delivery at end of next month, delivery at end of subsequent month. E.g. on 15 January 1920 the contracts for delivery were: 31 January 1920, 28 February 1920 and 31 March 1920.

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  - With a total paid-in nominal value of at least 1 million Yen (approx. $0.5m).
  - If a firm already had shares traded on the futures market, subsequent issues need to have a paid-in nominal value of at least 500 000 Yen.

Futures data

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- We collect daily data from January 6, 1920 to August 28, 1923 (earthquake in September 1923 shuts the exchange for 2 months).

Local Markets and Stock E

Tokyo Stock Exchange

For February 2

Tone	Opening	—
	Noon	—
	Closing	—
General Tendency at Closs		—
Exchanges		High
Shippings		Dull
Spinning		Steady
Sugars		"
Miscellaneous		"
Rails		Stationary
Textiles		"

(A)

		Closing Quotations This morning	Previous day
N.Y.K. 50 Paid up	Feb.	97.00	96.30
	Mar	96.70	96.00
	Apr.	97.00	96.40
Do. New 12.1/2 Paid up	Feb.	36.10	35.50
	Mar	36.10	35.60
	Apr.	36.40	36.00
T.K.K. 50 Paid up	Feb.	—	—
	Mar	—	—
	Apr.	23.50	23.40
Do. New 12-1/2 Paid up	Feb.	—	9.50
	Mar	—	—
	Apr.	—	—
Fuji Gas Spinning Co., 50 Paid up	Feb.	104.90	104.10
	Mar	105.00	104.2
	Apr.	106.10	105.10
Do. New 25 Paid up	Feb.	35.90	35.80
	Mar	36.00	36.00
	Apr.	36.40	36.10
Toyo Sugar Co., 50 Paid up	Feb.	55.00	55.90
	Mar	55.30	56.10
	Apr.	55.70	56.00
Do New 35 Paid up	Feb.	21.70	21.60
	Mar	21.70	21.70
	Apr.	22.10	21.90
Tainan Sugar Co., 50 Paid up	Feb.	—	8.30
	Mar	—	8.40
	Apr.	8.50	8.60
Yokohama Stock Exchange 25 Paid up	Feb.	66.00	64.20
	Mar	66.70	64.30
	Apr.	67.00	65.00
Tokyo Stock Exchange	Feb.	128.60	125.00
	Mar	129.70	125.60
	Apr.	131.30	126.90
Do. New 2-1/2 Paid up	Feb.	101.30	97.40
	Mar	101.60	97.80
	Apr.	102.80	99.30

(B)

South Manchuria Railway 100 Paid up	Feb.	—	—
	Mar	—	—
	Apr.	—	—
Do. New 100 Paid up	Feb.	—	—
	Mar	—	—
	Apr.	—	—
Hokkaido Col. Sir. 50 Paid up	Feb.	46.40	—
	Mar	46.80	45.20
	Apr.	47.00	45.50
Tokyo Woolen Cloth 50 Paid up	Feb.	—	—
	Mar	42.20	42.00
	Apr.	42.90	42.40
Tokyo Silk Woolen Cloth	Feb.	—	—
	Mar	—	—
	Apr.	—	—
Toyo Muslin 50 Paid	Feb.	103.30	102.00
Teikoku Hemp 50 Paid up	Feb	48.30	—
	Mar		
	Apr.	49.20	—
Do. New	Feb	—	11.40
	Mar	—	11.60
	Apr.	—	11.50
Nippon Hemp 50 Paid up	Feb.	—	—
	Mar	52.90	—
	Apr.	53.40	—
Do. New 12-1/2 Paid up	Feb	20.00	19.50
	Mar	20.20	—
	Apr.	20.70	19.90
Nippon Milling 50 Paid up	Feb	44.80	44.10
	Mar	45.30	—
	Apr	45.30	45.00
Toa Milling 25 Paid up	Feb.	16.40	16.20
	Mar	16.80	16.60
	Apr.	16.50	16.50

Bank of Japan Account

February 3

(in thousand yen,

	Today's	Previous
Convertible notes issued	1,261,159	1,292,791
Reserve	1,062,660	1,062,538
Issue Excess	78,499	110,254
General Loan	312,775	337,012

Tokyo Bankers' Clearing Return

February 3

Bills	¥93,788,357.39
Balance	13,322,211.99

Tokyo Rice Spot Quotations

February 2

Interest rate data

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- Assume rates for longer maturity are equal to 1 month rate.

Theoretical Pricing

- For futures pricing to preclude arbitrage (between contract pairs) the following relation needs to hold between all possible contract pairs (e.g. 1-month and 2-month, 2-month and 3-month and 1-month and 3-month):

$$F_T = e^{r(T-t)} F_t$$

If prices do not follow this relationship, then arbitrage profits exist.

Theoretical pricing, cont'd

- Example: On 1 Jan 1921, we observe:
  - Jan future = 50.
  - Feb future = 51.
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- Short 1 February contract: revenue = 51 Yen.

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- Short 1 February contract: revenue = 51 Yen.
- Take delivery of the stock at end-Jan and deliver at end-Feb.
- To perfectly arbitrage this we would need to be able to enter into forward rate agreement (i.e. contract today to borrow for 1 month at the end of January). The extent to which this is difficult or costly will reduce arbitrage opportunities.

Mispricing

- We calculate mispricing as the observed futures price (for the longer term contract) less the predicted price for the longer term contract (given the observed shorter term futures price) and normalise by dividing by the observed longer maturity futures price:

$$\epsilon = \frac{F_T - \frac{d(t)}{d(T)} F_t - \frac{PV_t - PV_T}{d(T)}}{F_T}$$

We do this every day for every contract pair. We calculate root mean squared errors (averaged over time) for each firm-pair.

Dividends and other oddities

- The TSE produced a yearbook, from which we are able to obtain dividend information. Unfortunately, it is only monthly.

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- We remove pairs when there has clearly been a capital operation.
- We also remove contracts maturing at end of April 1920. Stock exchange was closed part way through month due to panic following collapse of Chinese export market.

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Firm	All	1-2	1-3	2-3
Kanegafuchi Cotton (40 yen)	0.0092	0.0072	0.0114	0.0086
Nisshin Cotton	0.0217	0.0197	0.0265	0.0179
Kanegafuchi Cotton (50 yen)	0.0116	0.0082	0.0139	0.0120
Tokyo Stock Exchange	0.0096	0.0078	0.0118	0.0090
Yokohama Stock Exchange	0.0318	0.0106	0.0522	0.0114
Dai Nippon Sugar	0.0165	0.0160	0.0201	0.0128
Fuji Gas (50 yen)	0.0349	0.0327	0.0420	0.0280
Tokyo Stock Exchange (new)	0.0078	0.0067	0.0099	0.0064
Nippon Yusen Kaisha	0.0114	0.0102	0.0124	0.0111
Jomo Muslin	0.0300	0.0136	0.0476	0.0130
Ensuiko Sugar	0.0220	0.0113	0.0342	0.0101
Toyo Muslin	0.0311	0.0260	0.0386	0.0261
Tokyo Woollen Cloth	0.0204	0.0248	0.0180	0.0186
Toyo Sugar	0.0602	0.0436	0.0816	0.0418
Nippon Kinematographe	0.0202	0.0180	0.0234	0.0183

Firm	All	1-2	1-3	2-3
Toyo Cotton	0.0418	0.0395	0.0493	0.0336
Fuji Gas (25 yen)	0.0130	0.0136	0.0142	0.0109
Fuji Paper	0.0215	0.0242	0.0199	0.0209
Dai Nippon Fertilizer	0.0346	0.0184	0.0392	0.0395
Tokyo Muslin	0.0237	0.0123	0.0280	0.0256
Kinogawa/Kidagawa Power	0.0138	0.0116	0.0161	0.0122
Hokkaido Col. Str.	0.0142	0.0113	0.0157	0.0142
Toa Milling	0.0532	0.0256	0.0782	0.0322
Nippon Mlng./Japan Flr. Grd.	0.0240	0.0157	0.0320	0.0182
Teikoku Hemp/Imperial Linen	0.0294	0.0159	0.0417	0.0162
Nippon Hemp/Linen	0.0659	0.0158	0.0996	0.0187
Tainan Sugar	0.0535	0.0505	0.0614	0.0424
Toyo Kisen Kaisha	0.0272	0.0281	0.0305	0.0196
South Manchuria Rail	0.0308	0.0351	0.0345	0.0105
AVERAGE	0.0271	0.0198	0.0346	0.0193

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- We run a simulation exercise to estimate, given volatility and trade frequency, the anticipated mispricing if the data were asynchronous.
- If 2 futures contracts for the same firm were priced correctly at a moment in time, but possibly observed at different times during the same day $\epsilon = \frac{S_T - S_t}{S_T}$.

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  - Construct last-price-of-the-day spot prices for both contracts, $S_{n1}, S_{n2}, \dots, S_{n1339}$ and $S_{l1}, S_{l2}, \dots, S_{l1339}$.

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  - Calculate mispricing errors as $\epsilon_j = \frac{S_{lj} - S_{nj}}{S_{lj}}$.

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  - Calculate RMSE for this pricing pair over the 1339 days of generated data (the same period as covered by our actual data).

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  - Calculate mispricing errors as $\epsilon_j = \frac{S_{lj} - S_{nj}}{S_{lj}}$.
  - Calculate RMSE for this pricing pair over the 1339 days of generated data (the same period as covered by our actual data).
  - Repeat 1000 times and calculate an average.

Firm	All	1-2	1-3	2-3
Kanegafuchi Cotton (40 yen)	-0.0184	-0.0215	-0.0165	-0.0177
Nisshin Cotton	0.0108*	0.0084*	0.0156*	0.0075*
Kanegafuchi Cotton (50 yen)	0.0036*	-0.0002	0.0058*	0.0044*
Tokyo Stock Exchange	-0.0001	-0.0023	0.0019*	-0.0004
Yokohama Stock Exchange	0.0185*	-0.0032	0.0391*	-0.0016
Dai Nippon Sugar	0.0070*	0.0061*	0.0107*	0.0034*
Fuji Gas (50 yen)	0.0264*	0.0239*	0.0337*	0.0195*
Tokyo Stock Exchange (new)	-0.0030	-0.0041	-0.0009	-0.0043
Nippon Yusen Kaisha	0.0052*	0.0039*	0.0065*	0.0049*
Jomo Muslin	0.0171*	0.0004	0.0348*	0.0002
Ensuiko Sugar	0.0107*	-0.0003	0.0231*	-0.0010
Toyo Muslin	0.0165*	0.0111*	0.0242*	0.0116*
Tokyo Woollen Cloth	0.0049*	0.0091*	0.0027*	0.0030*
Toyo Sugar	0.0483*	0.0315*	0.0701*	0.0300*
Nippon Kinematographe	0.0062*	0.0038*	0.0095*	0.0044*

Firm	All	1-2	1-3	2-3
Toyo Cotton	0.0316*	0.0291*	0.0393*	0.0235*
Fuji Gas (25 yen)	-0.0005	0.0000	0.0008*	-0.0025
Fuji Paper	0.0106*	0.0132*	0.0093*	0.0100*
Dai Nippon Fertilizer	0.0124*	-0.0040	0.0174*	0.0171*
Tokyo Muslin	0.0104*	-0.0011	0.0148*	0.0123*
Kinogawa/Kidagawa Power	0.0043*	0.0019*	0.0066*	0.0026*
Hokkaido Col. Str.	0.0026*	-0.0005	0.0044*	0.0025*
Toa Milling	0.0244*	-0.0035	0.0496*	0.0033*
Nippon MIng./Japan FIr. Grd.	-0.0001	-0.0085	0.0081	-0.0059
Teikoku Hemp/Imperial Linen	0.0146*	0.0010*	0.0270*	0.0014*
Nippon Hemp/Linen	0.0470*	-0.0032	0.0809*	-0.0003
Tainan Sugar	-0.0372	-0.0405	-0.0286	-0.0488
Toyo Kisen Kaisha	0.0129*	0.0137*	0.0162*	0.0052*
South Manchuria Rail	0.0212*	0.0254*	0.0249*	0.0008*
AVERAGE	0.0106*	0.0031*	0.0183*	0.0029*

Which figures to believe?

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- then asynchronicity does not exist, and the unadjusted numbers give the best picture of how well investors priced futures.

Which figures to believe? cont'd

- If we believe that trades for one firm's futures, of a certain maturity, are independent of the trades of that firm's other maturity futures, then asynchronicity does exist, and our method should accurately tell us how much mispricing we should expect to measure even if (at a point in time) mispricing does not exist.

Which figures to believe? cont'd

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- In reality, the situation is probably between these two extremes, and we have plausible bounds for the amount of "true" mispricing in the Japanese futures market.

How big is big?

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  - OneChicago is not a very liquid market. We compare the 22 (out of 1300) futures which are more liquid than the least liquid firm we study on the TSE.
  - OneChicago uses marking to market, which needs to be treated carefully in valuing futures. We use the method of Hillard and Reis (1998) to measure pricing errors, using the LIBOR yield curve.

Firm	All	1-2	1-3	2-3
Apple	0.0130	0.0121	0.0125	0.0166
Research in Motion	0.0195	0.0187	0.0202	0.0216
Citigroup	0.0598	0.0549	0.0757	0.0544
Bank of America	0.0303	0.0341	0.0254	0.0224
Freeport McMoran	0.0317	0.0280	0.0417	0.0357
Goldman Sachs	0.0267	0.0253	0.0320	0.0245
JP Morgan	0.0200	0.0195	0.0202	0.0222
Google	0.0142	0.0139	0.0149	0.0145
Amazon	0.0173	0.0186	0.0151	0.0142
Qualicomm	0.0151	0.0146	0.0164	0.0153
Nucorp	0.0181	0.0156	0.0267	0.0131

Firm	All	1-2	1-3	2-3
Walmart	0.0086	0.0090	0.0080	0.0063
Exxon Mobil	0.0128	0.0102	0.0195	0.0090
Gilead	0.0123	0.0126	0.0125	0.0101
Johnson and Johnson	0.0088	0.0081	0.0127	0.0051
Wells Fargo	0.0301	0.0245	0.0484	0.0347
Sears	0.0462	0.0357	0.0723	0.0443
Morgan Stanley	0.0492	0.0465	0.0393	0.0799
CME	0.0268	0.0230	0.0333	0.0291
US Steel	0.0265	0.0270	0.0280	0.0107
Microsoft	0.0144	0.0172	0.0073	0.0116
Intel	0.0177	0.0154	0.0269	0.0189
AVERAGE	0.0239	0.0223	0.0277	0.0236

Firm	All	1-2	1-3	2-3
Apple	-0.0008	-0.0001	-0.0027	0.0018*
Research in Motion	-0.0048	-0.0043	-0.0051	-0.0035
Citigroup	0.0119*	0.0094*	0.0256*	0.0045
Bank of America	-0.0056	-0.0008	-0.0116	-0.0143
Freeport McMoran	0.0024*	-0.0006	0.0120*	0.0061*
Goldman Sachs	0.0016	0.0006	0.0064*	-0.0011
JP Morgan	-0.0082	-0.0082	-0.0084	-0.0063
Google	-0.0018	-0.0017	-0.0014	-0.0017
Amazon	-0.0039	-0.0021	-0.0065	-0.0073
Qualicomm	-0.0004	-0.0008	0.0007	-0.0005
Nucorp	-0.0077	-0.0098	0.0006	-0.0130

Firm	All	1-2	1-3	2-3
Walmart	-0.0015	-0.0010	-0.0022	-0.0040
Exxon Mobil	0.0000	-0.0025	0.0066*	-0.0040
Gilead	-0.0019	-0.0014	-0.0018	-0.0042
Johnson and Johnson	-0.0003	-0.0009	0.0036*	-0.0040
Wells Fargo	0.0038*	-0.0015	0.0219*	0.0081*
Sears	0.0171*	0.0069*	0.0430*	0.0151*
Morgan Stanley	0.0101*	0.0078*	0.0001	0.0406*
CME	0.0005	-0.0030	0.0068*	0.0025
US Steel	-0.0039	-0.0029	-0.0027	-0.0200
Microsoft	-0.0001	0.0028*	-0.0073	-0.0030
Intel	0.0009	-0.0013	0.0100*	0.0021
AVERAGE	-0.0055	-0.0053	-0.0023	-0.0028

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- A similar calculation for Japan renders 11 of the 59 contract pairs insignificant.

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- We include dummies for contract pair type.
- We also include a dummy variable based on whether ϵ was negative. These would be contracts where the arbitrage would require holding a short position in the stock.

Regresion results: Japan (unadjusted)

Variable	Estimate	t-stat	Estimate	t-stat
Constant	0.0156	5.4779	0.0167	5.8722
Dneg	0.0029	1.8918	0.0008	0.7378
Dneg*D13			0.0053	2.5058
Dneg*D23			0.0005	0.9462
D13	0.0065	7.7737	0.0042	6.8994
D23	0.0015	4.3720	0.0012	2.6934
AVGT	-0.0111	-3.6930	-0.0112	-3.7468
Sigma	0.0015	0.9002	0.0015	0.9101
Size	-0.0023	-4.0494	-0.0024	-4.0663
R^2		0.039		0.041

Regression results: Japan (adjusted)

Variable	Estimate	t-stat	Estimate	t-stat
Constant	0.0106	4.3538	0.0117	4.7253
Dneg	0.0029	1.9127	0.0008	0.7573
Dneg*D13			0.0052	2.4723
Dneg*D23			0.0006	1.0773
D13	0.0072	8.6757	0.0049	8.4023
D23	0.0013	3.8083	0.0010	2.3394
AVGT	-0.0040	-1.4162	-0.0042	-1.4729
Sigma	-0.0311	-28.3145	-0.0311	-28.3759
Size	-0.0021	-3.7218	-0.0021	-3.7112
R^2		0.1346		0.1365

Regression results: OneChicago (unadjusted)

Variable	Estimate	t-stat	Estimate	t-stat
Constant	-0.0006	-0.1330	-0.0000	-0.0099
Dneg	0.0020	1.0963	0.0010	0.6489
Dneg*D13			0.0039	1.8289
Dneg*D23			0.0011	0.6417
D13	0.0021	1.5069	-0.0003	-0.2592
D23	-0.0012	-0.5944	-0.0019	-0.7007
AVGT	-0.0063	-1.8010	-0.0064	-1.8053
Sigma	0.0260	6.1567	0.0260	6.1263
Size	-0.0008	-0.4859	-0.0008	-0.4768
R^2		0.1257		0.1268

Regression results: OneChicago (adjusted)

Variable	Estimate	t-stat	Estimate	t-stat
Constant	-0.0025	-0.5317	-0.0019	-0.4053
Dneg	0.0020	1.0938	0.0010	0.6396
Dneg*D13			0.0040	1.8706
Dneg*D23			0.0012	0.6542
D13	0.0013	1.0548	-0.0011	-1.0091
D23	-0.0009	-0.4413	-0.0016	-0.6155
AVGT	-0.0032	-0.8806	-0.0033	-0.8917
Sigma	-0.0084	-1.8015	-0.0083	-1.7790
Size	-0.0006	-0.3357	-0.0006	-0.3264
R^2		0.0153		0.0167

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- Some "arbitrage opportunities" in modern market.
- Slightly more in early 20th century Japan, but only for 1-3 pair. Other pairs can be explained by asynchronicity.
- Negative RMSEs hint that we may have correlated trading, perhaps caused by arbitrageurs.